18.—THE GEOLOGY AND PHYSIOGRAPHY OF THE GOSNELLS AREA

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I. INTRODUCTION.

The Gosnells Area lies 15 miles south-east from Perth, on the long, straight Darling Scarp which separates the low-lying plain (on which Perth stands) from the level Darling plateau whose surface is about 1,000 feet above sea level. The Darling Scarp here forms the western boundary of the Pre-Cambrian rocks which outcrop over so much of Western Australia.

In the eastern part of the country shown on the locality plan, the main rock type is granitic, covered in the higher country by a capping of laterite. The granite is cut by quartz masses (mainly thin veins, but there is also a huge quartz "blow" at Gosnells) and by basic dykes. On the western margin of the granite, steeply-dipping, slightly metamorphosed Pre-Cambrian sediments of the Cardup Series outcrop from Gosnells intermittently southwards.

The Cardup Series and granitic rocks close to the contact at Armadale were studied in 1939 (Prider, 1941), and, in 1940, areas were mapped at Gosnells and at Wongong-Cardup, respectively north and south of Armadale. At the end of the description of the Wongong-Cardup area (Thomson, 1941) the knowledge gained and the problems arising from the study of all three areas have been summarised.

The Gosnells Area is a strip of the scarp about 4 miles long and 1½ miles wide. Particular attention was paid to the northern part where the Cardup Series and quartz blow crop out, and the granite, basic dykes and quartz are exposed in quarries. The country was mapped entirely by pace- and compass-traversing by the writer working alone. These traverses were tied frequently to the Lands and Survey Department's pegs. Form lines were drawn from levels obtained by aneroid barometer readings, working from Gosnells railway station as datum.

II. PHYSIOGRAPHY.

A. *General Features.*

East of the present foot of the Darling Scarp, there was originally a laterite-covered peneplain (Jutson, 1934, p. 201). This peneplain was later elevated and youthful, westerly-flowing streams have now removed the laterite and exposed the underlying pre-Cambrian rocks along a belt, generally from half a mile to two miles wide. Pre-Cambrian rocks are exposed farther east only in the valleys of the larger streams and in some monadnocks rising above the plateau.

B. *The Darling Scarp.*

As Jutson concludes (1934, p. 87), the elevation of the Darling peneplain was effected by faulting, but the present face of the Darling Scarp is to the east of the actual fault-plane. No trace of the fault was detected in the Gosnells area.

Woolnough (1918, p. 390) believes there were two periods of uplift of the peneplain. After the first movements, mature valleys were formed which now occupy so much of the inland "wheat-belt" country; and later movements elevated the peneplain to its present height.

The topography of parts of the Gosnells area is composite, and supports Woolnough's belief. This is especially marked in the valley of Ellis Brook, which is mature above a height of 620 feet (the top of the Sixty Foot Falls). At and just below the falls, the stream bed drops over 100 feet and the sides of the valley steepen considerably. Upstream are some meanders, now slightly entrenched. In many other places, the scarp flattens above a height of about 500 feet. Clarke and Williams (1926, p. 167) note that terraces at a height of 450 feet in the Helena valley probably record a pause in uplift along the Darling fault.

As mature valleys were produced in the first cycle, more time must have passed between the two movements than has passed since the last uplift. But until we have more quantitative data of the rate of erosion of the local granite, we cannot suggest the absolute age of either movement.

C. *Streams.*

None of the streams draining the area can be described as the "major" stream. Most of them are short, flow due west down the scarp and may be explained as consequent on uplift of the peneplain. Jutson (1934, p. 169 and figure p. 171) states that the initial drainage of the elevated peneplain was to the south-east. Traces of a south-easterly drainage (now reversed so that the streams flow north-west) are found in the north-eastern corner of the country mapped. Generally, the northern sides of the valleys of streams flowing west are steeper than the southern.

Ellis Brook rises in the highest part of the area and flows a little to the north of west. It cuts through the quartz "blow" at one of its thinnest and weakest points: in this way its course has been determined by geological structure.

The course of stream B is more complex than that of the other young, westerly-flowing streams. It flows due west for most of its course, but for about 250 yards it runs a little to the west of north, parallel to the major joint-direction of the surrounding granite. Its tributary stream C has captured the head waters of stream D, and a wide, shallow wind-gap now separates the pirate and the beheaded streams.

D. *Remnants of the Peneplain.*

High, laterite-covered country of faint relief extends over most of the eastern part of the area. It has already been mentioned (under "General Features") that the peneplain (or, as it is now, the plateau) has been very completely preserved outside the Gosnells area.

E. *Effect of Geology on Topography.*

The different geological formations are unequally resistant to erosion. The quartz masses, by far the most resistant, stand up as isolated hills and occupy the crests of ridges. Basic dykes, as they are so much softer, cannot easily be traced through the quartz "blow"—in a short visit one may gain the impression that the quartz "blow" does cut the dykes. But though they are marked by depressions where they cut the quartz ridge, the dykes may be followed through the quartz by isolated boulders and red soil.

Generally the basic dykes are the most resistant of the other rocks; followed by granite, and lastly sediments (quartzite, conglomerate and shale in order). The edge of the laterite plateau may sometimes be marked by a breakaway, capping a steep scarp up to 30 feet high, but more often both breakaway and scarp are absent.

F. *Springs.*

In many places just below the laterite level, patches of greener vegetation mark the site of water seepages. So great is the amount of water which percolates through the laterite that Wright Brook and streams B and C are perennial. The only "spring" which does not issue from beneath the laterite is a small one by the side of a dyke in the quartz "blow," seven chains north-east of the Mountain Quarry. It flows only in the winter months.

III. Structure and Distribution of the Rocks.

A. *Xenoliths.*

Small fairly equidimensional fragments of more basic rock have been found in the granite. Some of these xenoliths are gneissic, but the orientation of their banding is very irregular. In size they range from large masses 15 feet across to almost entirely assimilated wisps, so that some of the specimens classed in the field as "granites" may actually be hybridised.

There is also a large doubtfully xenolithic elongated body found near the edge of the granite, north of Ellis Brook, which is shown on the map as "Chloritic Schist." Its borders have been weathered away, so that its relation with the granite and basic dykes cannot directly be determined. The schist trends a little to the west of north, and contains several irregular quartz veinlets which in general strike north-south and dip east very steeply. Quartz veins, about two feet wide, may be traced from the granite into the schist. They resemble other quartz veins from the area, which, it will be shown, were formed at a late stage in the cooling of the granite. Thus, the schist existed before the granite had completely cooled, and it is probably a xenolith in spite of its dyke-like outcrop.

Although a large number of xenoliths was noted near Gosnells, they are actually insignificant in bulk compared with the host-rock, and, except for the chloritic schist, these small masses are not shown on the map. Innumerable xenoliths are found at Armadale (Prider, 1941, p. 29) and small xenolithic fragments occur in the granite as far north as Statham's (Clarke and Williams, 1926, p. 169).

B. *Granite.*

The granite of the area is nearly all massive, and even in the better exposures in the quarries no flow structures were detected (although these may have been largely obscured on the stained joint-surfaces forming the walls of the quarries). Faint flow-layers (and, in two places, flow-lines) are found in isolated outcrops and boulders in the extreme south and in the north-east. The strike of the flow-layers is east of north, but very variable, and their dip is to the east at 40° to 70°.

It is impossible yet to say whether the massive granite grades into or intrudes the more gneissic granite of the south of the area. Mapping and detailed petrological examination of the country immediately to the south may reveal whether the granites are the same or different.

C. *Acid Intrusives into Granite.*

Dykes of aplite and pegmatite cut the granite, but they are too short and thin (none was over two feet wide) to be noted on the map.

Quartz veins have also been found, and they intrude the pegmatites. They usually outcrop strongly, and many of them are large enough to be shown on the map. Near most quartz veins, the granite is altered and has been weathered away. The edge of the quartz "blow" shown on the map is the edge of a zone of decomposed granite throughout which quartz veins occur.

Thin quartz veins (from an inch to three feet wide) have a general north-south trend (of 22 directions measured, 14 lay between 340° and 40°). Such thin quartz veins, however, rarely persist for over a chain. A larger quartz vein, nearly 100 feet wide, forms the crest of the steep northern slope of stream A and crops out over a distance of about half a mile on a course just north of east.

A large family of veins makes up the quartz "blow." It may be traced for 1¾ miles till it is lost under the laterite cover to the east. Small pebbles of milky, sub-angular quartz in laterite nearly a mile farther east are probably derived from an extension of the "blow."

Near its southern end, the quartz body consists of four or five parallel veins (each about one chain wide), spread over a width of 20 chains. Between these veins, the underlying rock is obscured by soil and by quartz talus. In quarries and cliffs in the "blow," however, schistose quartz sericite rock and thin quartz veins are exposed between the strongly outcropping veins.

The "blow" runs slightly obliquely to the course of individual veins. The latter trend about 30° south of Ellis Brook, and between 50° and 90° farther north. Vertical major joints are common in quarries and cliffs, and strike 135° near the White Rock and Mountain Quarries and 65° north of Ellis Brook. Sericite schist and quartz are roughly banded near the Mountain Quarry: the strike and dip of these bands (strike 20°, dip west at 60°) may possibly be the strike and dip of some of the veins. The banding may be thought to be a relict sedimentary structure, and the quartz "blow" to be a huge xenolith of sedimentary rock in which quartzose bands now appear as quartz veins. But there is no further sign of sedimentary structures even near the centre of the mass, and petrologically, both in hand specimen and in thin section, the quartz of the "blow" resembles that of the smaller veins, and is thus igneous in origin.

The acid igneous solutions from which the quartz veins are derived rose along planes of shearing and faulting in the granite. But, as the granite is structureless, there is no apparent explanation why these directions of weakness trend predominantly slightly east of north.

Many of the quartz veins have been examined for gold. The large vein just north of stream A has received particular attention. Five costeens have been dug in it, and Messrs. Ross and Son, in 1909, put in an adit-crosscut 175 feet long and a shaft 27 feet deep. The State Mining Engineer, A. Montgomery, visited the prospecting allotment and reported (1910, p. 124) that "the reef is very poor indeed in gold and quite unpayable at present." The cross-cut was extended 40 feet, but mining was then abandoned and nothing has since been done.

The quartz of the "blow" was recently quarried as an aggregate for concrete and for bitumen roads, but owing, it is said, to the heavy wear of the rock-crushing machines, it has not been worked since 1929.

D. *Cardup Series.*

This series outcrops west of the granite, near Ellis Brook. It strikes nearly due north, parallel to its contact with the granite and dips west at (usually) 50° to 55°. The dip steepens to vertical near the barite pits, but this is due to buckling by the nearby basic intrusion. Faint jointing, practically normal to the strike, is developed in the slates, but no fracture cleavage or dragfolding was noted.

Outcrops are poor, and sandstone rubble often obscures slate and conglomerate beds. There are thin bands and lenses (from an inch to six inches thick) of arkose in slate and bands of sandstone in conglomerate, so that the succession deduced from exposures in pits just north of Ellis Brook has been slightly generalised. It is, in descending order:—

Hematitic Sandstone	? (Western boundary obscured.)
Sandstone with Cherty lenses ..	30 feet.
Slate	20 feet.
Conglomerate	24 feet.
Vughy Sandstone (with barite) ..	8 feet.
Basal Conglomerate	15 feet.

Although coarser-grained than those which have been worked at Armadale and in the Wongong-Cardup Area, the Gosnells slate is of excellent quality for brickmaking. Shallow trenches have been dug to prove its extent and it is expected that, although the slate crops out over such a small area, it will be worked in the near future.

The contact between sediments and granite is nowhere exposed, but it may be mapped within five feet on the hill just north of Ellis Brook, and within 10 yards in several other places. No granite apophyses are found in the sediments, and small quartz veins in the granite may continue right to the contact but do not intrude the sediments, just as has been found at Armadale (Prider, 1941, p. 30). This indicates that the Cardup series is younger than the granite and quartz veins, a conclusion which is consistent with their very low grade of metamorphism.

E. *Basic Dykes.*

All previously mentioned rocks have been intruded by epidiorite dykes. Most of these dykes trend slightly west of north with dips (where measurable) to the east at 60°. A few trend north-west, or very rarely, due west.

Their width varies from five inches to about five chains—it is usually about a chain. In the centre of the wider dykes exposed in the quarries, "ladder" joints (Balk, 1937, p. 97) are developed perpendicular to the dyke walls, but their marginal three feet is schistose and contains segregations and veins of quartz, pyrite, calcite and epidote. Epidote veins may thread the epidiorites and also enter the surrounding granite.

Thin, irregular, basic veins (nowhere more than two feet wide) have been exposed in the White Rock Quarry. They occupy joint-cracks in the granite and resemble the schistose margins of the dykes in mineralogical composition.

A porphyritic basic rock (porphyritic epidiorite) intrudes the Cardup sediments. The dumps of two shallow pits dug in this rock contain small masses of barite, up to about four pounds in weight. Nothing is now visible to indicate further the mode of origin of the mineral.

Non-porphyritic epidiorite dykes intrude the Cardup series at Armadale (Prider, 1941, p. 43), but no such intrusions were found over the small area where the sediments crop out at Gosnells.

F. *Edge of the Pre-Cambrian Rocks.*

The western boundary of the Pre-Cambrian rocks cannot be drawn accurately. Some small, isolated masses of granite are found several chains west of the edge of the continuously outcropping granite. These may be outcrops, and may be boulders. Granite fragments are found in a well, 20 feet deep, 200 yards W.N.W. of the Mountain Quarry, far from any granite outcrop and 100 yards west of the nearest quartz outcrop. Near the Seaforth Home, a quartz mass extends far west of other outcrops. But in spite of these irregularities, and other irregularities due to laterite in the south, the boundary runs fairly straight in a north-south direction.

Outcrops of the Cardup series are very discontinuous. They are found next at Kelmscott, 3½ miles farther south (Honman, 1912, p. 63). They may exist, however, under the laterite rubble which is so common in the south of the Gosnells area.

Tertiary beds, found in bores near Perth, are probably developed west of the Pre-Cambrian rocks. A sub-artesian bore (depth 172 feet) was put down near Gosnells in 1872 Its exact location cannot be ascertained—it is mentioned by Brown (1873, p. 10), who stated that (among other things) fragments of lignite had been reported from the bore. Evidently the bore was put down entirely in the younger rocks west of the Pre-Cambrian: Simpson (1916, p. 173) called them "Mesozoic sandstones and shales."

G. *Laterite.*

As the laterite has been studied mainly in the field, it is best to discuss it at length now. There are two distinct types: high- and low-level laterite.

1. *High-Level Laterite.*

The edge of this capping lies at a height of between 700 and 850 feet above sea level. Although in places it is marked by a "breakaway"—a scarp (up to 30 feet high) topped by a few feet of solid pisolitic laterite,—more often the edge of the laterite is covered by a few feet of sand and rubble so that it cannot be mapped with certainty. Furthermore, laterite is found in places at a level below that of the breakaway only a short distance away. North of stream A, there is a small outcrop, 30 feet below the scarp, and north of Wright Brook, a ridge about 50 feet below the breakaway, projects for ¼ mile. These outcrops are separated from the main plateau by rubble which in other places extends for 200 feet below the breakaway. Detritus obscures most granitic outcrops over the whole scarp east of the Seaforth Home, but it is now being cut through by a stream.

A pit has been dug a chain away from and a few feet above the edge of the laterite outcrop, east of the White Rock Quarry. It passes through about 30 feet of laterite, underlain by pink and white clay. Laterite must therefore extend below the level of the breakaway, and, as has just been mentioned, its boundary is likely to be obscure, especially where there is no breakaway.

As the laterite capping formed (Woolnough, 1918) on the surface of the peneplain, differences of laterite level are due to initial relief of the peneplain. The thickness of the capping probably rarely exceeds the 30 feet found in the pit (above). In places, it is much thinner, for epidiorite fragments have been found well above the base of the laterite.

2. *Low-Level Laterite.*

Near the foot of the Darling scarp, laterite crops out in places, west of all outcrops of Pre-Cambrian rocks. In a gravelpit just west of the Mountain Quarry, the deposit grades from ill consolidated detrital material mixed with large quartz boulders to more homogeneous laterite. Small "breakaways" in laterite have been noted (e.g., at a height of 300 feet near the south-west corner of the area, and at a height of 180 feet, west of the White Rock Quarry). The laterite may not be all detrital in origin.

Near Ellis Brook, just west of the porphyritic epidiorite, is a red, clayey deposit with incipient pisolitic structure—perhaps a partially formed laterite. The heavy minerals of this clay and of the porphyritic epidiorite were almost exclusively magnetite, so it may be suggested that here the porphyritic epidiorite (or some other rock of favourable composition and texture) is being laterised *in situ*. But all that can definitely be asserted is that, near Gosnells at least, the low-level laterite is too discontinuous to mark the position of a step-faulted block, as suggested by Woolnough (1919, p. 16).

H. *Later Superficial Deposits.*

These include silt, sand and talus slopes. A little silt has been deposited in the valleys of the larger streams, but it is not shown on the map. Sand occurs over the laterite on the gently-sloping plateau and over low-level laterite near the plain. Except for the lateritic rubble which covers such a lot of the area, talus slopes are small.

IV. PETROLOGY.

A. *Xenoliths.*

Although in the field these are much darker, some contain only a little more biotite than does the surrounding granite, so that the two rock-types are very similar in section.

Usually, the biotite is a green variety (X = light yellow Y = Z = dark green) with inclusions of opaque magnetite (?) aligned parallel to c. In particularly biotitic rocks, recognisable felspar crystals are rare, their place being taken by masses of finely granular epidote. Epidote may be found, too, as coarse, turbid and red stained granules associated with biotite aggregates. Quartz is subordinate to biotite and epidote. Sphene (in the form of scattered granules) and apatite are rare. Most of the xenoliths are these biotitic rocks more or less digested by the plagioclase- and quartz-rich granite.

Potash felspar is found in very few of the xenoliths. Plagioclase is saussuritised and sericitised to a varying extent; and some individuals contain small columnar crystals of zoisite. Extinction angles measured on albite twin lamellae indicate that the felspar averages Ab_{63}, with a range in composition from Ab_{56} to Ab_{98}. In rocks containing heavily sericitised felspar, the biotite has recrystallised to coarser green flakes. Sometimes, this process is incomplete and leaves the biotite intergrown with muscovite or with colourless chlorite (?).

Occasional specimens contain a brown biotite (X = light yellow, Y = Z = deep copper-brown). Such a rock (with granular epidote marking the place of felspar) is found at Statham's. Clarke and Williams (1926, p. 169) noted that such "biotitic segregations" exist, but they did not describe them.

The Gosnells xenoliths resemble the hornblende-biotite-zoisite hornfels xenoliths found at Armadale (Prider, 1941). They are, however, much more digested by the granite magma. Hornblende has disappeared, and apatite is much rarer. Quartz (and plagioclase in the more assimilated rocks) have been introduced, and epidote has recrystallised to coarser granules.

A rather different type of material is the chloritic schist, which resembles one, but only one xenolith, near the foot of the scarp north of Ellis Brook. The former is green, fine-grained and finely banded (about 15 bands to the centimetre). The constituent minerals found in thin section are quartz, chlorite, magnetite, muscovite, and a little epidote and apatite. Alternate bands are rich in quartz and in chlorite and magnetite, and the minerals are usually elongated parallel to the banding. The quartz veinlets seen in the field are found, on a small scale, in a thin section. As a result of weathering, hematite has been formed from the magnetite and has discoloured the rock, and consequently it was impossible to compare specimens of the schist from both sides of stream A.

An epidiorite dyke alongside the schist contains abundant green chlorite, but the schist resembles most closely a dark, massive xenolith found near Ellis Brook. The xenolith is made up magnetite, biotite, apatite, sericitised felspar and muscovite; a higher grade assemblage than occurs in the schist. Sericite is abundant in the schist, to the exclusion of felspar, of which it is the alteration product: apatite is less common; biotite has been converted to chlorite and quartz has been introduced as bands and veinlets. In both rocks, the sericite has been partially recrystallised to small flakes of muscovite.

From its field occurrence the schist is considered to be a xenolith, permeated by siliceous solutions derived at a late stage of cooling of the granite. Near quartz veins in the area, granite is generally altered to a schistose aggregate of low-grade minerals: similar changes in a xenolith have produced the schist.

B. *Granite.*

A hand-specimen of this rock is medium, even-grained and either light coloured, or tinted red by weathering. The minerals recognisable are limpid quartz; pink, greenish or white felspar and flakes of biotite.

The texture is allotriomorphic granular (or occasionally poikilitic) and the minerals found in thin sections are quartz, a plagioclase near albite and some microcline with dark minerals (biotite, chlorite and epidote) very subordinate. Table I. shows the range of mineralogical composition of the granite.

Plagioclase in all the rocks sectioned is of positive optical character, and in most of them the maximum extinction angle on the albite twin lamellae is 12° to 15°, indicating a composition between Ab_{91} and Ab_{97}. The average composition is then the same as that of plagioclase in the xenoliths, but its range is narrower.

The plagioclase in some of the granites is saussuritised. In most, however, it is sericitised, and it has been found in all stages of alteration from being perfectly fresh to being completely replaced by sericite. These alterations must be primary: they are too widespread and independent of jointing and other means of ingress of water to be regarded as due to weathering. Plagioclase in the pegmatite and aplite dykes is remarkably fresh. In a few granites, too, plagioclase is only slightly sericitised, and in these rocks as much saussuritisation has taken place as sericitisation. These rocks are rich in microcline, and under the microscope several of them shown signs of crushing and even of faulting of small displacement.

TABLE I.

Micrometric Analyses of Gosnells Granites.

(Figures are volume percentages.)

	1.	2.	3.	4.
Quartz	37·9	35·1	34·6	37·4
Plagioclase	47·7	46·7	37·8	19·7
Microcline	10·4	13·1	24·4	38·7
Muscovite	1·6	1·8	...	0·1
Biotite	1·6	0·2	0·5	2·8
Chlorite	0·8	1·2	2·6	...
Apatite	0·1	...	...	...
Epidote	...	1·7	...	1·0

1. Granite containing sericitised plagioclase. Road Board Quarry (for analysis *see* Table II., column 1) specimen 20,696*.

2. Granite containing saussuritised and sericitised plagioclase. Specimen 20,709.

3. Granite containing clear felspar and a crush breccia. The analysis is of the uncrushed part. The crush breccia occupies 14 per cent. of the section. Specimen 20,706.

4. Granite: gneissic with slightly turbid but unsericitised plagioclase. Specimen 20,701.

* The numbers refer to catalogued specimens in the General Collection at the Geology Department, University of Western Australia.

TABLE II.

Analyses of Darling Range Granites and of Certain "Average" Types.

	1.	2.	3.	4.	5.
SiO_2	75·01	73·49	73·36	73·30	75·99
TiO_2	0·20	0·14	0·04	0·11	0·09
Al_2O_3	13·14	14·24	13·88	12·33	13·14
Fe_2O_3	1·08	0·88	0·84	2·58	0·93
FeO	1·39	0·92	0·93	1·28	0·24
MnO	0·01	tr.	0·15	0·02	...
MgO	0·02	0·43	0·51	0·26	0·08
CaO	0·26	1·84	1·69	0·46	0·62
Na_2O	3·96	3·86	3·22	4·55	3·92
K_2O	4·00	3·42	5·07	4·20	4·70
H_2O+	0·28	0·55	0·18 }	0·86 {	0·27
H_2O-	0·30	0·08	0·11 }		0·08
CO_2	...	0·07	...	...	...
P_2O_5	0·07	0·01	0·07	0·05	...
BaO	0·08	0·07	0·09	...	0·03
FeS_2	...	0·01	0·05	...	...
	99·80	100·01	100·19	100·00	100·09

The alkalis were determined in a granite from Statham's by C. R. Le Mesurier in 1929; giving Na_2O 4·25; K_2O 2·31 per cent.*

1. Granite: Road Board Quarry, Gosnells. Analyst: C. E. S. Davis.
2. Granite: Government Quarry, Boya. Analyst: J. N. A. Grace.*
3. Granite: Mahogany Creek. Analyst: A. J. Robertson (Simpson, 1916, p. 18).
4. Alkaline Granite: Average of 10 analyses (Daly, 1933, p. 10).
5. Kalialaskite: Average of six analyses (Johannsen, 1932, p. 49).

* Published by kind permission of the Government Mineralogist and Analyst.

Potash felspar is always much fresher than the plagioclase, and any alteration is by kaolinisation, not sericitisation. As it always shows grid-iron twinning, it has been described as microcline. No orthoclase was recognised in any section of a granite. Occasionally, thin strings of clear quartz thread the potash felspar, forming an injection micropegmatite.

Quartz is found as clear grains which always show wavy extinction. Next to felspar, it is the dominant mineral.

Biotite has the pleochroic scheme X = light yellow, Y = Z = deep brown, but in many rocks it has changed to the green variety which may be interlaminated with colourless chlorite (?) and muscovite. The green biotite, too, may be replaced and pseudomorphed by weakly birefringent green chlorite.

Epidote, if present, usually forms coarse turbid granules associated with biotite, as it does in the xenoliths. Rocks containing this type of epidote are, then, slightly hybridised. Epidote in the veins emanating from the epidiorites is colourless to canary yellow and clear.

Short stumps of apatite are rare constituents of the granite. They are larger and more prominent in completely sericitised rocks.

Occasionally sericite has partially recrystallised to muscovite, which is developed both as anhedra within the parent plagioclase and as laths between the plagioclase grains.

An analysis was made of an albite-rich granite in which the albite was moderately sericitised (it is estimated that about 20 per cent. of the albite has been replaced by sericite). The result is shown in Table II. in which it is compared with other granites analysed from the Darling Ranges near Perth, and with two "average" types.

The main point of difference between the Gosnells granite and the other two granites near Perth which have been analysed is its extreme poorness in magnesia and lime. It is slightly poorer in alumina, and slightly richer in silica, titania and both iron oxides. The total alkalis in all three rocks are fairly constant, although there is considerable variation in the relative proportions of potash and soda.

Of Daly's average rock types (1933, p. 9) the Gosnells granite resembles most closely the alkaline granite (Table II., column 4), but is decidedly low in ferric oxide, a little low in magnesia, lime and the alkalis; but richer in silica and alumina. Johannsen's "kalialaskite" (Table II., column 5) has, like the Gosnells rock, a low magnesia and lime content.

From the mode of the Gosnells granite (Table I., column 1), its alkali content can be calculated to be Na_2O 5.6% K_2O 2.0%. The excess potash found in the analysis must be due to the sericite flakes, and to a little potash-felspar in solid solution in the plagioclase.

The plagioclase of the granite probably crystallised as a solid solution containing up to 30% of potash felspar. The solubility of the two diminishes rapidly with fall in temperature (Johannsen, 1932, p. 141), and the excess potash-felspar normally separates as antiperthite. In the Gosnells granite, sericite is found instead of perthitic intergrowths: the potash-content of the plagioclase separated as sericite, which is stable at a low temperature and (especially) under conditions of stress. Some rocks contain unsericitised plagioclase and much potash-felspar, and many of these microcline-rich rocks show signs of crushing. The plagioclase probably recrystallised under the stress, and later, smaller stresses produced the faulting now visible. In pegmatite and aplite dykes, which crystallise at a lower temperature than the parent granite, original plagioclase was comparatively free from potash-felspar, and little sericite has since formed.

C. *Acid Intrusives.*

1. *Pegmatite and Aplite.*

These two types are often associated, and in such instances the pegmatite occupies the border and aplite irregular patches in the centre of the intrusion. Coarse crystals scattered near the edge of an aplite dyke are seen in section to be resorbed. Emmons (1940, pp. 5-6) points out that the outstanding difference between pegmatite and aplite is textural: if the volatile constituents escape from a liquid which is crystallising as a pegmatite, the residuum will solidify as a fine-grained aplite.

The pegmatites consist of plagioclase, microcline, microperthite or graphic intergrowth of quartz and microcline, together with quartz and small books of muscovite. The grain size of the pegmatite is up to 10 cm., but that of the aplites is only 0.3 mm.

The plagioclase in both types of rock, as mentioned previously, has been remarkably little sericitised. Microcline is usually subordinate to plagioclase. Quartz, though fairly common, is not as abundant as it is in the granite. One aplite contained a few rods of muscovite and a few laths of tourmaline (pleochroic scheme X = deep blue, Z = colourless) but no dark minerals.

2. *Quartz Masses.*

As described in the section on their field characters, quartz masses may be from an inch to over 20 chains wide. In spite of this tremendous difference in their size, all such masses appear to be of similar character.

The central parts consist mainly of fine-grained massive white quartz. In thin section, they are made up of irregular interlocking grains of quartz of very uneven texture (in one section the grain size varied from 0.03 mm. to 0.5 mm. and in another from 0.2 mm. to 1 mm.) Undulose extinction is very common, and is especially noticeable in the larger grains.

Some of the quartz from near the centre of the "blow" is friable and "sugary" and contains numerous small flakes of sericite. This sericite content increases towards the edge of the mass, but nowhere has much sericite recrystallised to muscovite. On the west side of the Mountain Quarry, sericitic and quartzose bands are interleaved. In other places near the edge of its outcrop, the quartz "blow" is made up of a stockwork of tiny quartz veins (about 1 cm. wide) in a micaceous matrix. This is especially clear on weathered surfaces. "Shaly bands" noted in weathered rock near the edge of the "blow" consist entirely of an aggregate of small flakes of sericite.

The granite is generally weathered away for some 50 yards from the edge of the quartz outcrops. Where granite does outcrop in the immediate vicinity of the larger quartz masses, it contains stockworks of quartz, flanked by crushed and silicified granite containing bands rich in sericite. Most of the thinner quartz veins are surrounded by flaky, dark, weathered rock.

Sericite and subordinate green biotite have been introduced in cracks through the original felspars in apparently massive granite threaded by quartz veinlets. Occasionally the twin lamellae of the felspars are bent; otherwise they are not altered. Quartz, as it is not unduly strained, must have been introduced after the stresses operated to deform the felspar. Other specimens of granite, which can be seen in hand-specimen to be altered, contain felspar in various stages of replacement by sericite. So rock types are known, in the wall-rocks and in the quartz masses, which are transitional between granite and pure massive quartz.

It has been held that the quartz "blow" is merely recrystallised quartzite xenolithic in the granite. But there is no trace of bedding in the "blow" (except possibly the sericitic bands found in the Mountain Quarry). It is unlikely that such a large scale structure would be obliterated elsewhere. Recrystallisation, too, should produce a mass of even-grained quartz and muscovite, and no stockworks of quartz threading the surrounding granite.

Thin sections from the "blow" and from narrow quartz veins resemble one another. Both contain evidence of replacement, and because so many transitional rocks are found, it is concluded that all these masses (including the wide "blow") were formed by hydrothermal replacement.

Similar quartz veins (both in width and nature) occur near the Great Bear Lake, Canada. The wall-rock (a granodiorite) is altered for distances of up to 100 feet from the edge of the quartz veins. Such alteration (Furnival 1935, p. 855) consists of the replacement of felspar by secondary minerals (chiefly sericite), followed by replacement of original and secondary minerals by quartz. Furnival concludes (p. 859) that the hydrothermal solutions passed along faults of great persistence and displacement along which the rocks were severely fractured over widths of up to 1,000 feet. Similar faulting in the massive granite near Gosnells, although it cannot yet be proved, is nevertheless possible. The quartz was probably derived from end-stage solutions from the granite, as no other acid igneous rock has been found in the district.

The long quartz vein north of stream A contains small scattered crystals of pyrite which weather easily to make the rock appear vughy and to stain it reddish-brown, green and yellow. Iron oxide has been deposited by percolating water in many places in the adit, which cuts through the vein 90 feet below the surface.

Veins 1 cm. wide, rich in blue-grey tourmaline, cut the quartz of the White Rock and Mountain Quarries. The quartz of these veins is colourless, limpid and coarse-grained (the grain size is up to 1 cm.) but excessively strained. The tourmaline is in the form of wisps or rods, aggregating to an irregular fibrous mass with pleochroic scheme X = deep blue, Z = pale brown. The refractive index $\epsilon = 1.628 \pm 0.003$ indicating a tourmaline about midway between dravite and schorlite (Winchell, 1927, p. 246). Simpson (1931, p. 141) describes the occurrence of dravite in many places near Perth, and mentions that "In addition schorl has been detected in small quantities at Gosnells and Cardup."

D. *Cardup Series.*

1. *Arkose and Slate.*

Being intimately associated in the field, the two are discussed together.

Arkosic bands and lenses in the slate contain pebbles of quartz up to 5 cm. long, set in a mass of smaller grains of rounded quartz, more turbid felspar and (in weathered specimens) white kaolinite (?). Some slaty material is found in the arkosic patches.

The constituents present in sections are subangular quartz (grain size 0.1 mm. to 2 mm.), subordinate fresh microcline and a little slightly sericitised plagioclase, and rare aggregates of a flaky mineral of low birefringence which may be kaolinite, all set in a sericite cement. In weathered specimens, plagioclase and sericite are absent, but the clay constituent (a turbid, earthy mass) is abundant.

The slate is a fine-grained finely bedded micaceous rock. Fresh specimens are grey, and slightly weathered ones stained pink. It consists of sericite and oval shaped quartz grains about 0.05 mm. long, and a few small, rod-like idioblasts of tourmaline in various stages of development (the largest noted was 0.3 mm. by 0.1 mm.). The pleochroic scheme of the tourmaline is X = deep blue-green, Z = very pale blue.

Bedding of the slate is conspicuous and marked by orientation of the sericite and by iron-staining. Although hand specimens of weathered slate and of "shaly bands" from near the edge of the quartz "blow" resemble each other, they are very different in section. "Bedding" is irregular in the "shaly bands," the sericite is haphazardly oriented and not associated with rounded quartz grains, and quartz occurs only in veins composed of interlocking angular grains.

2. *Sandstone.*

Rocks classed as "sandstones" grade from sandy slates to porous quartzose grits resembling the arkoses. Bedding, though clear in the finer grained rocks, may not be noticed in the coarser ones.

The dominant constituent is quartz, in rounded grains up to 5 mm. long with wavy extinction. Sericite, present in small quantities as a cement in all the sandstones, is as common as quartz in the sandy shales. Felspar and tourmaline are rare, but rounded zircon plentiful.

A few veins, consisting entirely of an interlocking mosaic of quartz, thread the lower sandstone. Their grain size varies from about 0.1 to 0.5 mm. and in one specimen the grains of the vein quartz were noted to be larger than those of the surrounding sandstone. Strain shadows may be noticed in the larger grains. Cherty lenses in the middle sandstone band have a conchoidal fracture and consist of fine (0.05 mm.) interlocking grains of quartz.

As the lower sandstone is very vughy also, it appears that material has been dissolved out of the rock to leave the vughs and has been redeposited elsewhere in the same bed as veins. The vughs (which are up to 3 cm. in diameter) are lined with a thin layer of quartz, and within the vughs there are well developed crystals of barite up to 1 cm. long. A little barite is scattered through the sandstone, but no barite veins have been seen in this bed. However, in a cherty lens of the upper sandstone, there are barite veins.

The nearby intrusion of porphyritic epidiorite, which contains a segregation of barite, is probably the source of the barite found in the sandstone. It is suggested that barite-rich solutions dissolved some material out of the sandstone, forming the vughs which they later incrusted with quartz and barite: this suggestion may be tested by finding out (at Armadale and southwards) whether the vughy sandstone is always baritic.

3. *Metamorphism.*

Metamorphic effects in the Gosnells sediments are very slight. Tourmaline has developed in the slates, and sericite may be recrystallised. In the sandstones, a little quartz recrystallised at some stage as cherty lenses and as quartz veins. But hematite has not been changed to magnetite, and no biotite has developed. Only slight jointing has been produced. Argillaceous sediments are very readily affected by rise of temperature, and the very slight metamorphism of these rocks indicates that they were deposited after the granite had cooled.

E. *Basic Intrusives.*

1. *Uralitised Quartz Dolerite (Epidiorite).*

Hand specimens of this rock are grey to greenish-black in colour and are fine-grained near the edge of the dykes, but medium-grained near the centre. They consist of white felspar set in a darker matte of amphibole. Essential minerals present in thin section are felspar, amphibole, epidote and ilmenite. Most of the amphibole is a pale variety consisting of flaky aggregates or irregular plates, and is evidently a secondary mineral. It is referred to as "uralite." A little primary brown amphibole is present in most rocks, and bluish, more euhedral amphibole is produced by recrystallisation of the uralite. Both these latter types of amphibole are referred to as "hornblende."

In similar basic dykes north of Gosnells (e.g., in the Lower Chittering area (Miles, 1938, p. 29)), uralite is derived from pyroxene. The author has seen a section of a dyke near Darlington in which pyroxene has partly altered to a pale green uralitic aggregate which farther from the parent mineral, has recrystallised to a blue-green type of hornblende. Although no relics of the primary, high-grade parent mineral of the uralite have been found in the Gosnells area, it is believed that this uralite, too, is derived from pyroxene.

Holmes (1928, p. 92) defines "epidiorite" as "A doleritic or basaltic rock in which the augite has suffered alteration to hornblende so that the rock (mineralogically) approaches the composition of a diorite." The writer has added the word mineralogically as, chemically, such alteration does not produce a more acid rock.

Basic dykes near Perth with pyroxene entirely replaced by hornblende have been described in previous literature as "epidiorite." This has, however, become a field- and a sack-name and moreover has often been altered to "diorite," even in geological publications. It is best, therefore, to give to the rocks a name indicating their genetic relationships, and they are here termed uralitised quartz dolerites. Uralitisation must have been deuteric, for the Cardup sediments are so very low-grade that there could have been no regional metamorphism to effect the change.

Fresh primary felspars are clouded and coloured brown, but this colouration is far less marked than it is in dolerites from Darlington and Lower Chittering. MacGregor (1931) suggested that, were a basic intrusive heated at some period after its consolidation, minute traces of impurities, of which iron oxide is the commonest, would separate, resulting in grey- and brown-clouding. He contends (p. 537) that:—

> "it seems necessary to prove that (any igneous rock with clouded felspars) . . . can never have been subjected to regional- or contact-thermal metamorphism before the clouding can be regarded either as an original feature of the felspar or as a deuteric effect that arose at a late stage in the consolidation period."

In the Gosnells area, there are no later intrusions to effect contact metamorphism and, as has just been shown, no regional metamorphism can have taken place. Clouding, then, was produced either at a primary or at a deuteric stage. Recrystallised epidiorites from Gosnells contain unclouded felspar, and felspars in Gosnells epidiorites are far less clouded than those from basic dykes farther north. In the Lower Chittering, Miles (1938, p. 31) notes that clouding was especially marked in the unaltered dolerites. It appears that clouding is best developed in the rocks which have undergone least deuteric alteration, and is therefore an original feature of the felspars.

The least recrystallised dolerite from Gosnells contains abundant uralite as irregular fibrous aggregates or irregular plates with the following optical properties: pleochroism X = very pale green, Y = pale green, Z = pale brown; extinction $Z \wedge c = 22°$ and (—) 2V large. Along edges adjacent to felspar, part of the uralite has recrystallised to blue-green hornblende (pleochroic scheme X = pale green, Y = grass-green, Z = blue-green, $Z \wedge c = 23°$). There are occasional crystals of euhedral primary brown hornblende (X = light yellow-brown, Y = deep green, Z = deep green-brown).

The plagioclase is generally fresh with a slight brownish smoky coloration, and has a maximum extinction angle of 32° in sections cut normal to the albite twin lamellae, indicating a composition of about Ab_{45}. In some rocks, however, plagioclase has been entirely replaced by an aggregate of turbid, colourless epidote, and epidote has elsewhere gathered into a mass of clearer laths and granules. Other constituents of the rock are leucoxene (with a small core of ilmenite), laths of apatite and a little interstitial micropegmatite. The ophitic texture of dolerites has been well preserved.

A similar dyke from the Bickley Brook Reservoir Quarry, one mile north of the area, has been analysed (Clarke and Williams, 1926, p. 173). It contains more blue-green hornblende, and a little brown hornblende in the central parts. Some of the felspar has been converted into a mass of epidote, but other crystals are brown and smoky.

In some rocks, the felspar is always replaced by a turbid mass of epidote and the ophitic texture lost. Hornblende in this type of rock (a lighter blue-green variety) forms crystals with very irregular borders. Quartz and micropegmatite are common, and, in certain segregations, dominant. The felspar of the micropegmatite is extensively sericitised.

Nodules and veins of epidote are scattered through the dykes exposed in the quarries in the Gosnells area. The dolerite surrounding a nodule, spherulitic in structure, was totally recrystallised to a non-porphyritic medium-grained (grain size 2 mm.) ophitic intergrowth of clear albite felspar and pale green hornblende. The albite contains a few pale green inclusions and both albite and hornblende are very similar in this rock and in a fresh porphyritic epidiorite (4. below) from farther south. The pleochroic scheme of the hornblende is X = pale yellow; Y = Z = pale green, and its refractive index β is 1.641, compared with 1.657 in primary brown hornblende from the Bickley Brook Reservoir Quarry.

A little of this hornblende has been converted to biotite. However, another recrystallised specimen (about three feet from the edge of a dyke) contains much biotite so that it resembles biotite epidiorites, described in the next section.

A few veins of calcite, up to 3 cm. wide, occupy prominent joint cracks in the dykes. Some pyrite, too, has crystallised with the calcite in and near the veins. The rock surrounding calcite veins is very low grade: it consists of pale green chlorite, quartz and turbid patches of calcite.

Occurrence of Galena.—The author has seen two loose specimens of galena from Gosnells, but, in spite of a long search, none in situ. One, from a dump at the Blue Rock Quarry, contains a mass of galena about 1 cm. in diameter, set in coarse, strained and slightly granulated milky quartz. According to quarrymen, it came from a mass of quartz adhering to the granite at the dyke contact on the west wall of the north quarry, but no galena-bearing quartz could be found in situ.

The other specimen, from the White Rock Quarry, was collected by S. E. Terrill early in 1935. Now that so much further quarrying has been carried out, it was impossible to recognise the dyke from which it came. His specimen is a fine-grained, rather schistose, dark rock, with fine disseminated grains of galena and pyrite. It contains a little residual green hornblende and biotite, but the main ferro-magnesian is chlorite. Other minerals present are clear recrystallised albite, very subordinate epidote and a quartz vein containing some calcite.

This occurrence of galena at Gosnells, although on a very small scale, is interesting because the galena is definitely associated with the uralitised quartz dolerite or one of its derivatives. It throws light on the genesis of the galena-sphalerite-quartz veins of Armadale (Prider, 1941, p. 51) and silver-lead deposits at Mundijong (Esson, 1927), and confirms Prider's suggestion that they are genetically related to the basic rather than to the granitic magma.

2. *Biotite Epidiorite.*

A dyke, 10 feet wide, exposed only in the southern corner of the White Rock Quarry, is the sole rock found of this type. It contains many calcite veins and numerous small brown rounded biotitic patches. A section cut from the centre of the dyke shows that the pale blue-green hornblende has been largely altered to brown biotite—the brown patches consist of a decussate aggregate of biotite flakes. Recrystallised albite is common. Near its edges, the dyke consists of a fine-grained mass of green biotite with subordinate epidote and leucoxene, and clear felspar is rare.

These rocks are similar to those described by Prider (1941, p. 46) from Armadale which, being chemically very rich in potash and poor in lime, resemble the chlorite-albite epidiorite and, probably, the porphyritic epidiorite (4. below). But the Gosnells rock seems to be a derivative of the uralitised quartz dolerites, altered by end-phase potassic solutions.

A narrow epidotic biotite epidiorite dyke (five inches wide) in the White Rock Quarry is firmly welded to the granite. It consists of epidote and (especially near its margin) of green-brown biotite. Microscopic veins of biotite and chlorite penetrate the granite for at least ½ cm. both between and through its constituent crystals, and cause a bending of the albite twin lamellae of the felspar. In composition, this dyke is intermediate between the biotite epidiorites and the biotite-epidote veins.

3. *Biotite-Epidote Veins.*

These thin veins (maximum width two feet) are, unlike the dykes, irregular and not persistent.

The vein material is aphanitic, green or black and flaky, evidently containing abundant biotite. Indeed, it consists of green biotite (largely converted to chlorite) and very pale green epidote. Granite inclusions in the vein are cut by stringers of biotite and epidote. Albite twin lamellae of the felspar in the xenolithic rock are bent and fractured, but the felspar is clear and unsericitised and may have recrystallised before these deforming movements took place.

4. *Porphyritic Epidiorite.*

This type is found only near Ellis Brook, where it intrudes the Cardup sediments. Porphyritic epidiorites occur at various places (Wongong, Cardup, Mundijong) farther south, and a similar non-porphyritic rock at Armadale (Prider, 1941, p. 43).

It is a dark, weathered rock made up of laths of felspar, up to 5 mm. long, set in a fine-grained ground. From a section, it is seen that felspar is developed as stout prisms (of all sizes from ½ mm. to 5 mm.) which form a coarse network. The felspar is near albite, contains abundant chloritic inclusions and is little altered except for slight kaolinisation. The ferromagnesian constituent is now green to brown biotite, forming decussate aggregates, filling the interstices between the network of albite prisms. Magnetite is fairly common.

Small lumps of barite have been found near a pit in the porphyritic epidiorite. The mineral is associated with veins of strained quartz, and is largely massive (grain size 0.3 mm.), but is also developed as tabular crystals up to 5 cm. long. As this is the sole occurrence of barite in association with any igneous rock in the area, the porphyritic epidiorite is probably the source of the barite in the Cardup sandstones at Gosnells.

V. GEOLOGICAL HISTORY.

There is no record in this area of any event prior to the emplacement of a granite batholith in middle Proterozoic time (Clarke, 1930, p. 160), although a little to the south large masses of earlier, more basic rocks are preserved (Prider, 1941). These have been largely digested by the granite at Gosnells, and only a very small quantity of them is found as xenoliths.

End-liquids circulating in joints formed in the cooling mass crystallised as dykes of pegmatite and aplite. Stresses at a later stage fractured the granite over a wide zone, and quartz was deposited from hydrothermal solutions over this zone and in many smaller fractures.

There followed a period of erosion and deposition of a normal sequence of sediments (the Cardup series) which have undergone very little anamorphism. Although only a small thickness of sediments is exposed at Gosnells, several hundred feet are exposed farther south, and a considerable thickness may underly the surface rubble even at Gosnells.

All pre-existing rocks were invaded by basic dykes of (Clarke, 1930, table p. 187) late pre-Cambrian age. These dykes now contain the lower-grade mineral hornblende instead of pyroxene. In a porphyritic basic dyke, a segregation of barite was formed. At the same time, probably, baritic solutions entered the more porous basal beds of the Cardup series.

Since pre-Cambrian times, a great thickness of sediments has been laid down in the trough west of the Gosnells area. In the Tertiary (Woolnough, 1918) a laterite capping was developed over the peneplained surface of the pre-Cambrian rocks. The peneplain was uplifted (in at least two stages) and a small amount of subsequent erosion produced the present topography.

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